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PROCEEDINGS
OF THE
LINNEAN SOCIETY
OF
NEW SOUTH WALES,

WEDNESDAY, MARCH 27TH, 1907.

The Thirty-second Annual General Meeting, and the Ordinary Monthly Meeting, were held in the Linnean Hall, Ithaca Road, Elizabeth Bay, on Wednesday evening, March 27th, 1907.

ANNUAL GENERAL MEETING.

Mr. T. Steel, F.C.S., F.L.S., President, in the Chair.

The Minutes of the preceding Annual General Meeting (March 28th, 1906) were read and confirmed.

The President delivered the Annual Address.

PRESIDENTIAL ADDRESS.

The remembrance of the Society's well-sustained activities during the past year, and a hopeful outlook for the future may very well encourage us to celebrate the thirty-second anniversary in no despondent frame of mind, notwithstanding the fact that very important and unlooked for changes, affecting the personnel of the Society in almost every grade, have transpired since the last annual gathering. The removal of Dr. J. P. Hill to London, to take up the work of Professor of Zoology at University College, following close upon that of Mr. Waite to New Zealand, has deprived us of an active worker of the stamp that we much prefer to welcome rather than to lose. Mr. P. R. Pedley, one of the oldest Members of the Council, has found it necessary to withdraw; and in starting upon his visit to Europe on a well-earned holiday Mr. Pedley will take with him our best wishes for an enjoyable and invigorating trip, and a safe return in due course.

Since the last Annual Meeting we have had to deplore the deaths of Dr. Sylvanus P. Langley, an Honorary Member, Mr. William Mitten, a Corresponding Member, the Hon. William R. Campbell, M.L.C., and Mr. Alexander Grant, Ordinary Members, and Mr. Frank E. Grant, F.L.S., and the Hon. Dr. James Norton, Members of the Council.

As philosophers we with fortitude recognise the inevitable vicissitudes—accessions and departures—which enable the guild or corporation not only to develop, but to remain intact and immortal. Still, as "units of humanity," we cannot but feel a deep sense of personal regret at the loss of our comrades and the severance of old associations.

Dr. Samuel Pierpont Langley, the distinguished Secretary of the Smithsonian Institution, and *ex officio* keeper of the United States National Museum, Washington, died on February 27th, 1906. His conspicuous success as an administrator and his zealous efforts to develop the usefulness of these great Institutions with their various ramifications, and to uphold their prestige, have amply justified his selection to carry on the work inaugurated by Professor Joseph Henry, and worthily continued by Dr. Spencer Fullerton Baird. Dr. Langley had established his reputation also as an accomplished astronomer and physicist especially interested in the problems of æronautics. His decease has removed an influential and worthy disciple of science and source of inspiration not only to his own countrymen but to the wider brotherhood of science. Professor Langley was elected an Honorary Member of this Society in August, 1891, in succession to his predecessor Professor Spencer Baird, in token of the

Society's appreciation of the inestimable services rendered by the Bureau of International Exchanges of the Smithsonian Institution, which so liberally interprets the term "diffusion of knowledge" as to recognise therein the necessary but prosaic labour of distributing the publications of Scientific Institutions, which is done entirely free of charge.

Mr. William Mitten, the accomplished English bryologist, and father-in-law of Dr. Alfred Russell Wallace, who passed away in his eighty-seventh year, at Hurstpierpoint, Sussex, on July 20th, 1906, was elected a Corresponding Member of the Society in March, 1882. His professional work, that of a pharmaceutical chemist, gave him little opportunity for travel, even as far as London; but this led him all the more assiduously in his leisure time to cultivate at home an early acquired taste for botany, until, botanically speaking, he must have come to know by heart the neighbourhood in which he was born, lived out his simple but fruitful life, and in which he ended his peaceful days. Through the influence of his friend and neighbour, William Borrer, and also of Sir William Hooker, he was led eventually to specialise in the study of mosses, hepatics and lichens; until, in this branch of botany, he became one of the leading British authorities. His published papers are very numerous; and one of them, entitled "Musci Austro-Americani," by itself takes up the entire twelfth volume of the botanical portion of the Journal of the Linnean Society of London (1869). His more important papers on Australian non-vascular cryptogams are "A List of the Musci and Hepaticæ collected in Victoria, Australia, by Dr. F. Mueller (in Hooker's Journ. Bot. viii. 1856, pp.257-266); "Descriptions of some new species of Musci from New Zealand . . . together with an enumeration of the Species collected in Tasmania by William Archer, Esq.," &c. (Journ. Linn. Soc. Bot. iv. 1860, pp.64-100); also the "Hepaticæ," and in conjunction with the Rev. C. Babbington, the "Lichenes" of Hooker's "Flora Tasmaniæ" (1860). In addition to these, his contributions to knowledge include studies on some or other of these groups from New Zealand, Fiji, and Samoa; as well as from Japan, and Mt.

Kinibalu in Borneo. To Mr. Botting Hemsley's "Report on the Botany of the Challenger Expedition," Mr. Mitten also contributed the portion dealing with the hepatics and mosses.

Mr. Mitten has thus furnished us with a brilliant and inspiring example of the useful and necessary amateur at his best, and of the extraordinary amount of good work that can be successfully accomplished during the frequently interrupted leisure of a long lifetime by the patience and concentration of an enthusiast. I may conclude my remarks upon this estimable man by a brief quotation from a biographical sketch, contributed to the "Journal of Botany" (for October, 1906) by Mr. Botting Hemsley, who says of Mr. Mitten—"He had correspondents in all parts of the world, from whom he received many things besides mosses, including seeds for his garden, of which he was very fond. I remember how keenly he examined his mosses and liverworts for chance seeds of other plants, and how much pleasure he derived from observing their germination and growth. In this way he raised several things from remote islands visited by the 'Challenger' Expedition."

The Hon. William Robert Campbell, M.L.C., a member of an old Sydney family, who died on July 30, 1906, aged 68, joined the Society in October, 1878. At this time he was the owner of Trigamon Station, near Warialda; and becoming interested in the occurrence of fishes in a dam unconnected with any water-course, and which had been dry a few months previously, he forwarded specimens to Sir William Macleay, who determined them to be referable to a species of *Therapon* (*T. unicolor* Gthr.), and published a short account of them in the Society's Proceedings (Vol. iii. p. 15). Upon relinquishing the life of a squatter, and taking up his residence in Sydney, Mr. Campbell developed a lasting interest in matters relating to fish and fisheries. For some years, and until its abolition, he was a member of the old Board of Fisheries; and a few months before his death he was elected to the existing Board, in succession to the late Hon. John Want, M.L.C. Mr. Campbell was elected to the Legislative Assembly, as Member for West Sydney, in 1868. From November, 1880, until his resignation in May, 1886, he was the representative of the electorate of Gwydir. In April, 1890, he was appointed to a seat in the Upper House. As a public man, and as a public-spirited citizen, Mr. Campbell enjoyed the respect and esteem of those who knew him or were associated with him in public life. Sir William Macleay and Mr. Campbell married sisters, two of the daughters of the late Sir Edward Deas Thomson, C.B., K.C.M.G. Mr. Campbell's death has thus deprived the Society of a member more nearly related to Sir William Macleay, than by the tie of personal friendship.

Mr. Alexander Grant was born at Cullen, Banffshire, Scotland, in 1844. He served his apprenticeship as a horticulturist in the celebrated gardens of the Earl of Seafield, Cullen House, being afterwards engaged as gardener in the Royal Botanic Gardens, Edinburgh, during the curatorship of Mr. McNab. His skill as a microscopist at this time led to his employment in the preparation of botanical microscopical material for the University students who attended the gardens for special study. After his arrival in Sydney, in 1878, he was employed for several years as a private gardener, and in 1882 joined the staff of the Sydney Botanic Gardens. Mr. Grant made a special study of fungi and was honorary custodian of the plants of this group in the National Herbarium. He was a Vice-President of the Horticultural Association of New South Wales since its foundation. Mr. Grant died on Christmas Day, 1906.

The comparative absence in Australia of a wealthy leisured class gives fewer unpaid workers to science in proportion to professionals than is the ratio in Europe. Those we have are busy men who, after their day's work is done, devote spare hours or holidays to study. One such, a brilliant amateur, was lost to our little band of workers when Frederick Ernest Grant succumbed, after a brief illness, on 31st January last. Mr. Grant was born 23rd March, 1866, at Farlesthorpe, Lincolnshire. In 1883 he accompanied an elder brother, engaged in pastoral pursuits, to New Zealand, and five years later entered the service of the Union Bank. His love for natural science was strong from boyhood. During his residence in Auckland he collected actively, and possessed a good knowledge of the local fauna. Transference to the Melbourne office opened for him a wider intellectual horizon, which he much appreciated. He attended the science courses at the Technical College and became an active member of the various scientific societies. At the excursions of the Field Naturalists his was a prominent and popular figure. In the Royal Society he rose to be a member of council. His artistic abilities were at the disposal of his friends, and he illustrated various papers by Messrs. Pritchard and Gatliff. Conchology and geology were at first his favourite subjects, but when Mr. T. S. Hall pointed out to him that these sciences had their devotees, while the crustacea lacked a local student, he turned his energies to carcinology and worked steadily at it for the rest of his life. In 1902 he enjoyed extended official leave and re-visited England. The British carcinologists, who recognised the merit of his work and its future promise, gave him cordial greeting. He studied the Australasian crustacea at the British Museum and made voluminous notes thereon. In 1902 he was elected a Fellow of the Linnean Society of London. Shortly after his return to Australia the Bank transferred him to Sydney. At once he took an active share in our scientific life, was elected member September 30th, 1903, and on the death of Mr. Trebeck succeeded to the vacant seat on the Council. In 1904 he helped to organise an expedition to examine the fauna of the Great Barrier Reef, and with the assistance of Mr. A. R. McCulloch presented to the Society a report on the Crustacea of Mast Head Island. At the time of his death he was busy with a second collection from the Barrier. He accompanied two deep-sea dredging expeditions. His report on the first is incorporated in our Proceedings; that on the second he did not live to finish. An article on the crustacea of Norfolk Island had just been completed before his decease and will be presented to the Society at an early date. He leaves a widow and three children.

The Hon. James Norton, LL.D., M.L.C., was born in Sydney, on December 5th, 1824. His father was an English solicitor, who came to Sydney in 1818 to practise his profession. At this time the legal fraternity in Australia comprised two English solicitors who received a retaining fee from the English Government as an inducement to take up the practice of law at the Antipodes. James Norton, jun., was articled to his father in 1843, was admitted as a solicitor in 1848 and subsequently taken into partnership. On his father's death in 1862, he succeeded to the business; and, with his partners, he ever afterwards worthily upheld the good name of the important practice so successfully initiated by his father. In 1879 he was called to the Upper House, and in 1884 he became Postmaster-General in the Stuart Government. Outside the field of politics, Dr. Norton patriotically served the State in several capacities—as a trustee of the Australian Museum from 1874; as a member of the Board of Trustees of the Free Public Library from 1878, and of which he was chairman at the time of his decease; and as a trustee of Hyde, Phillip and Cook Parks for many years, as well as in other ways. In his early days he seems to have developed a taste for natural history, which provided him with a never-failing hobby for the rest of his life. Some thirty years ago, when the publication of the "Flora Australiensis" made it possible for Australian students to take up the study of indigenous plants with satisfaction and profit, Dr. Norton was one of a small band which included Professor Stephens, Mr. R. D. Fitzgerald, Mr. Edwin Daintree and a few others whose names are not now ascertainable, who met together informally from time to time, to study and compare their collections, and to exchange experiences, with a view to mutual help and encouragement. He was an ardent horticulturist, and took great pride in the beautiful trees and shrubs, especially those of indigenous species, which he cultivated in his fine old garden, and many of which he had himself planted. The spring flowering of his magnificent collection of Cape bulbs furnished an annual occasion for assembling and extending a hearty welcome to his many friends. The natural history of his country home at Springwood was a perennial source of delight and refreshment. He spared and safeguarded the welfare of all the most attractive native plants on his estate, and completed the task of compiling a census of its flora. His observations on the birds were partially embodied in a paper entitled "Australian Birds: Useful and Noxious," read at the "Conference of Fruit-growers and Vine-growers" held in Sydney in June, 1890, and published in the Report thereof (p. 245). This interesting article concludes with some emphatic remarks upon the unrestricted and inconsiderate acclimatisation of undesirable alien species of plants and animals—a subject upon which, as a community, even to this day, we are so slow to learn wisdom. At the monthly meeting in July, in formally announcing his decease, I referred to Dr. Norton's long and honourable connection with the Society, of which he was the oldest surviving original member; to the Society's indebtedness to him for valuable services rendered in various official capacities; and to his unwavering support to and interest in the Society and its welfare. Dr. Norton was an observer rather than a writer; but the needs of a Society like this are so varied that the co-operation of members with similar qualifications, and with such ripe experience and general knowledge, is a most important source of strength.

The three extraordinary vacancies in the Council, due to the removal of Mr. Waite and Dr. Hill from the State, and the decease of Dr. Norton, were filled by the Council's election of Messrs. A. G. Hamilton, R. H. Cambage and Professor J. T. Wilson, in the manner prescribed by the Act of Incorporation, as announced in due course to the Members. In accordance with the provisions of Rule xvi., these gentlemen are included among the six retiring Members of Council for the year. More recently the retirement of Mr. Pedley, and the decease of Mr. Grant have caused two additional vacancies which remain to be filled on the present occasion, as Members have already been notified by circular.

Six (nominally seven) Ordinary Members, and one Associate Member were elected during the year, so that our numbers remain practically stationary. The thirty-seven papers read before the Society have been published, Part 4 of the Proceedings for 1906, containing the last instalment of them, being now ready for distribution. They presented a wide range of subjects for consideration, and in some cases called for ampler opportunities for discussion than the time available at the Meetings allowed, or until those interested had had the opportunity of seeing the papers in print. As soon as provision can be made for it, a special opportunity for discussing the topics treated of in the papers by Messrs. Andrews, Halligan, Taylor, and Dr. Woolnough will be afforded; and an announcement upon the subject may be looked for at the next Meeting.

The additions to the library for the year amounted to a total of 1,471 (including 127 Vols), received by gift or exchange from 203 Societies, &c., and 16 individuals.

Notwithstanding the fact that the time for repainting and renovating the exterior of the Society's premises arrived during the year and was duly provided for, I am glad to be able to say that the Hon. Treasurer will be able to announce presently that we began the current year with a credit balance from last Session.

During the year that has passed, the Macleay Bacteriologist has been engaged upon researches connected with that important bacterium, the nodule-former of the *Leguminosæ*. Although the presence of slime in the cells of the nodules and the occurrence of the same in artificial culture under certain conditions, have been known for some time, the real significance of the slime has not hitherto been demonstrated. His first research showed that the slime formed by the microbe contained as its essential constituent, a gum which appeared to approximate in some respect to the carbohydrate of certain nucleoproteids, and on this account the slime in the nodule probably serves to build up the nucleoproteids of the leguminous plant. Using the formation of slime as an index of the activity of the bacterium, it was shown that the bacteria from the nodules of various leguminous plants differed from one another physiologically. But from the fact that three European races of the micro-organism, which had been induced to reassume their slime-forming property in the laboratory, were physiologically identical, it is evident that the physiological function is mutable, and that the bacterium may adapt itself sooner or later to the conditions that occur within the root-hair and the nodule. There are great differences in the facility with which various races can produce slime under laboratory conditions. As some races do not form it at all, there is reason to believe that the failure of trade cultures of "Nitragin" has in the past been in part at least due to the fact that the importance of the slime-forming function has not been recognised. As they come from the nodules of various plants of the same species, the bacteria may be similar, just as they may be similar when taken from nodules of the same plant. But that such is not always the case, was shown by three distinct races having been obtained from a single nodule. The hypothesis has been advanced that the plant utilises the intracellular albuminoids of the bacterium for its nutrition. Dr. Greig-Smith has shown that this is not probable, for although the great majority of the bacteria and bacteroids are dead during the active growth of the plant, they still stain deeply, and therefore cannot be in process of solution. As the slime is nitrogenous, there can be no doubt that the hypothesis advanced by Mazé is correct, and that the slime is the means by which the nitrogen is conveyed from the bacterium to the plant. The inner structure of the bacterium has given rise to much speculation, and latterly its sporangium nature has been advanced. Mazé was the first to illustrate it as consisting of coccobacteria within a branching capsule. The Macleay Bacteriologist has shown that it consists of cocci within a branching capsule, and is therefore allied to *Leuconostoc* and *Streptococcus*. It has been shown that the most suitable medium for growing the slime is one which approximates in its nitrogen and salt content to soil-water, so that, while the bacterium is vegetating in the soil, the alkalinity and nutrients will sustain the slime-forming function. The carbohydrates of the root-hair are the chemotactic substances which induce the bacterium to enter the plant. A second research showed that the bacterium was capable of fixing atmospheric nitrogen upon synthetic media under certain conditions. These also induced the formation of slime. Races of the microbe which, while multiplying freely, could not form slime from particular nutrients, were incapable of fixing nitrogen, but when they did form slime from other nutrients a fixation also occurred. The presence of another bacterium, itself incapable of forming slime or of fixing nitrogen, increased the slime formation and the fixation of nitrogen. Finally, the fixation of nitrogen was proportional to the formation of slime. A number of lower forms of plant life are known to be capable of enriching the soil by fixing atmospheric nitrogen, and among them, *Azotobacter chroococcum* is possibly the most vigorous. The Macleay Bacteriologist has confirmed the researches of Beijerinck upon this micro-organism, and has also drawn attention to the fact that the nodule-former of *Leguminosæ* is quite as capable as *Azotobacter* of fixing nitrogen while it is vegetating in the soil.

Three pupils availed themselves of the facilities afforded by the Society's laboratory, and received instruction in certain branches of bacteriology. Dr. Greig-Smith is at present in Europe, on leave, familiarising himself with the recent advances in bacteriological science.

During the past twelve months Mr. H. I. Jensen, Macleay Fellow in Geology, has been continuing his work on the alkaline rocks of Eastern Australia. Early last year he completed the petrological investigation of the specimens collected in the Warrumbungle Mountains during the preceding year. He also visited Queensland to make some final observations in the field prior to the publication of his paper on the Geology of the Volcanic Area of the East Moreton and Wide Bay Districts, Queensland. On this expedition he discovered another area of glaucophane schists to the north of the Conandale Range and west of the Blackall Range in the Mary River valley. In May last year he was granted leave of absence to visit Samoa to study the geological features of the eruption in progress on the island of Savaii. After writing up his paper on Samoa and investigating the rocks collected in the islands, he resumed his work on the Australian alkaline rocks. Mr. Jensen commenced field work in the Nandewar Mountains, starting out from Narrabri; having examined the geology of this district and made a large collection of specimens, he drove across to Coonabarabran and finished his field work and collecting in the Warrumbungles, commenced in the previous year. From the Warrumbungle Mountains he proceeded to Dubbo to examine the alkaline rocks lately discovered there by Mr. Myrton, Geological Surveyor of New South Wales. He returned in the end of November after an absence of nearly three months. Since his return Mr. Jensen has been occupied with the petrological examination of the rocks collected, and is at present making chemical analyses of some of the most interesting types. Amongst the rocks collected were alkaline syenites, alkaline (arfvedsonite) trachytes, ægirine-nepheline phonolites and other alkaline rocks from the Nandewars; and nosean, pseudoleucite, nepheline phonolites, alkaline trachytes and pantellarites, sodalite and melilite basalts, &c., from the Warrumbungles. There is also a remarkable porphyritic sill rock from the Nandewars which may perhaps form a new rock-type. Mr. Jensen expects to have a paper ready by June or July, embracing all his work in the field and laboratory on the Geology of the Nandewars and Warrumbungle Mountains. I may add that the Council has reappointed Mr. Jensen to a Fellowship.

In response to the Council's offer of two vacant Linnean Macleay Fellowships two applications were received, one of which met with the approval of the Council. I have now much pleasure in availing myself of the first opportunity of formally announcing to the Society the name of the second Linnean Macleay Fellow, Mr. James M. Petrie, D.Sc. The particular branch of work which Dr. Petrie will follow is Biochemistry. Dr. Petrie's training has been such as to especially fit him for this line of research. Commencing at the Heriot-Watt Science College, Edinburgh, Dr. Petrie continued his studies at the University of Sydney where he completed a distinguished science course at the end of 1905. Among distinctions gained were first class honours and medal in chemistry at the B.Sc. examination of 1904; Caird Research Scholar in Chemistry (1904); and first class honours and medal in Organic Chemistry at the D.Sc. examination of 1905. Dr. Petrie is highly recommended by his instructors, and has had valuable experience both as a teacher and as an investigator. His published papers comprise a thesis for the D.Sc. degree, "The Mineral Oil from the Torbanite of New South Wales," published separately (Sydney, 1906) and also in a somewhat abridged form in the Journal of the Society of Chemical Industry, (Vol. xxiv., 1905), and "The Stinging Property of the Giant Nettle-Tree" (*Laportea gigas* Wedd.) in the Society's Proceedings for 1906. Dr. Petrie is now engaged upon important investigations upon the composition of Piturie, and upon the occurrence of strychnine in the native Strychnos tree of New South Wales; and at our last monthly meeting he was able to show a sample and to make a preliminary announcement concerning his isolation of a new midriatic alkaloid from the leaves of *Solandra lævis* Hook., a tropical American solanaceous plant cultivated in gardens. There is a very large and important field of work open for investigation in Australia, in the branch chosen by Dr. Petrie; and we look forward with the greatest interest to the results of his investigations. It is not expected that the volume of work should be great, for if it is to be useful it must be thorough, and thorough work in biochemistry can only be carried on at the expenditure of much time and labour.

The 23rd May ensuing will be the two-hundredth anniversary of the birth of Linnæus, the great Swedish naturalist. The University of Upsala has taken steps to commemorate this interesting event in a manner worthy of the occasion; and has honoured the Society by inviting it to send an official representative to participate in the rejoicings. Our geographical remoteness and the shortness of the interval may possibly prevent the acceptance of the letter of the invitation. But the Council has accepted its spirit by deciding to hold a Special Meeting, in honour of the occasion, on 23rd May, so that, as Members of a Society bearing the name of the illustrious Swede, we may have an opportunity of refreshing our memories upon such points as the salient features of his life, his teaching, and his influence; as well as upon the significance of our name, and the nature of the bond which unites us in a Society bearing that name. Fuller particulars will be announced at the next Meeting.

During the past year there has been more than usual literary activity in scientific circles in Sydney. Several members of the Society, as is well known, have been engaged in the task of bringing out books on special scientific subjects. The first work to make its appearance is that of Mr. D. G. Stead on "The Fishes of Australia," and after a careful examination of the book I can speak in the highest terms of its usefulness and value, and I congratulate him on the success which has attended its publication. I understand that Mr. Stead has been commissioned to bring out a report on the edible oysters of New South Wales, which will deal with the economic as well as the scientific aspect of the subject. Other members who have works in the press are Messrs. Lucas, Froggatt, Rainbow and Waterhouse, and as each is dealing with a subject in which he has special experience, we may look forward to some very valuable additions to Australian scientific literature. Among official publications issued during the year, were the continuation of Mr. Maiden's "Forest Flora," and Mr. North's "Catalogue of Eggs and Nests of Birds breeding in Australia and Tasmania."

The recognition of the value to the community of scientific guidance has, in many instances, in the past been so scanty that it is a pleasure to note a step in the right direction lately taken by the Government, in the appointment of committees of advice to assist the Public Service Board in respect to scientific and professional appointments in the Public Service, and in connection with the State Museums to discuss all matters affecting the scope and control of these institutions. Considering the objects in view, a wise selection has been made of the members constituting the committees, and there can be no doubt that their influence will be most beneficial.

It is with pleasure and satisfaction that, in the name of the Society, I take the first opportunity of officially welcoming back Professor David on his return from attending the great Geological Congress at Mexico and the meeting of the British Association in England, at both of which functions he very worthily upheld the scientific reputation of Australia.

Last year I alluded to the biological exploration of the Blue Lake, Mount Koscuisko, by Professor David and colleagues; and as it has since happened the examination then made was most opportune. A few months after Prof. David's visit, the Council of this Society learned that the Fisheries Department contemplated taking steps to stock the Blue Lake, amongst other inland waters, with introduced trout. The importance of a minute biological survey of undisturbed inland lakes is now thoroughly recognised, as witness the elaborate work being carried out on such in Britain, America and elsewhere, and the Council accordingly approached the Fisheries Board with a view to having the Blue Lake left undisturbed. The Board courteously replied that for the present the proposed introduction of trout would not be carried out. The Fisheries Board will, I am sure, support the efforts of this Society to retain intact some at least of the smaller patches of undisturbed water, for the benefit of science.

In last year's Address mention was made of a grant from the Royal Society of London to Professor Haswell for deep-sea dredging. The first expedition, which was made in June last, met with somewhat disappointing results owing to stormy weather. A second and very successful excursion was carried out in October, the spot dredged being about 35 miles east of Sydney, on the 152nd meridian, in 800 fathoms depth. By the use of the bucket dredge and a small trawl modelled on that recommended by the Prince of Monaco, a varied assortment of most interesting forms was obtained. The organisms secured by tow-netting at the first excursion have in part been already described in the Records of the Australian Museum. Descriptions of the animals procured on the second trip, by various authors, are well advanced and will be published shortly. I am pleased to say that the Royal Society of London and the Australian Association for the Advancement of Science have provided funds for further carrying on of dredging operations, and Admiral Field has placed a well-equipped sounding machine at the disposal of Professor Haswell.

SOME QUESTIONS IN TERRESTRIAL PHYSICS.

In the course of my address last year I dealt with some features of oceanic physics and incidentally with a number of phenomena having an important bearing on the study of certain great geological problems. The facts and speculations which I then placed before you were received with so much favour by members and friends that I have decided on this occasion to discuss a few interesting questions in terrestrial physics which have lately been occupying a prominent position in scientific thought.

RADIUM AND THE EARTH'S INTERNAL HEAT.—The very unexpected properties possessed by radium have elevated it to a position of prominence quite out of proportion to the relative extent of its occurrence in the earth's crust. Radium is probably the rarest—as regards quantity obtainable—of any substance so far isolated, and yet, so unique are its characteristics and so far-reaching are the possibilities attaching to its presence, that, though its very existence has only been known for a few years, it is now the subject of more experimental study than any other body. Briefly, the reason why so much interest centres round this substance is that it is considered to be in a state of disintegration, a condition accompanied by a hitherto quite unsuspected display of energy, manifesting itself in most remarkable ways. The study of the properties of radium has disclosed the existence of an enormous store of energy locked up in the constitution of matter, and it is the phenomena accompanying the liberation of this energy during the breaking up or disintegration of radium that render the subject one of such great interest and importance. The conclusion arrived at from careful observations on the rate of decay of radium is that a given unit of this substance has a life which may be stated as roughly about 2000 years. In other words, an ounce or a pound or a ton of radium would, in the course of some such period, no longer possess the peculiar properties of the original substance, and would have lost materially in weight.

Radium is generally supposed to be itself a product of the slow breaking up of uranium and certain other elements. Uranium compounds spontaneously, and at a definite rate, yield radium, which in turn breaks up, giving rise ultimately as its chief product to the gas helium. This latter substance was first detected spectroscopically in the sun, but is now known to exist in small amount in our atmosphere, in the water and gas emitted by springs, and in a number of minerals.

Opinions as to the precise nature of the phenomenon involved in the disintegration of radium are at the present time somewhat divided. The most generally held view is that we have here to do with a true case of atomic disintegration. the actual breaking up of a chemical element through the disintegration of its atoms, the integrity of which has hitherto been an axiom of chemistry. This is the opinion expressed by such capable observers as the Hon R. J. Strutt, Mr. Soddy and others, and, with some reserve, by Prof. Rutherford. On the other hand, it is considered by the veteran Lord Kelvin and by Prof. Armstrong that it may quite well be that the emanations from uranium, and in turn from radium, pre-exist as such, and are simply continually escaping from combination, that, in fact, radium may be merely a compound body liberated from uranium and in turn breaking up explosively. The contention of the latter authorities is that the atomic disintegration theory is not proved and that speculation has gone ahead of observation. This question, however, does not particularly concern the aspect of the subject with which I desire to deal on this occasion, so that its further discussion will not be necessary here.

I have already mentioned that the phenomenon which we have been considering is accompanied by the liberation of a relatively enormous amount of energy, the bulk of which makes itself manifest as heat. Assuming that uranium (or other radium-producing substance) is distributed in sufficient quantity through the earth's crust and that the disintegration phenomena with accompanying liberation of heat go on beneath, as they do at the surface, the production of this heat will have a most important bearing on internal terrestrial temperature, on volcanic activity, and, incidentally, on the great question of geological time.

Without going much into detail, it will suffice to state that different observers have determined with some degree of accuracy the proportion of radium contained in various representative rocks and minerals. The Hon. R. J. Strutt in particular has devoted much attention to this investigation and has found that the proportion varies greatly in different rocks. Acidic rocks such as granite are on the whole richest in radium, while basic ones such as basalt contain least. Minerals rich in uranium and certain other rare elements contain relatively large amounts of radium, the latter bearing in all cases a definite relationship to the uranium present; but these minerals are sparsely distributed and exist in insufficient quantities to materially affect the average composition of the earth's crust as regards radium content. Full details of Mr. Strutt's work on this subject were brought before the Royal Society of London in April, 1906.* The following figures express the proportion of radium existing in a few of the representative rocks examined by Mr. Strutt:—

Rock.	Density.	Radium per gram in grams.	Radium per c.c. in grams.
Granite	2·63	$9·56 \times 10^{-12}$	$25·2 \times 10^{-12}$
,, ...	2·62	9·35 ,,	24·5 ,,
,, ...	2·65	6·63 ,,	17·6 ,,
,, ...	2·64	2·45 ,,	6·47 ,,
Dolerite	2·95	1·24 ,,	3·65 ,,
Basalt	2·75	1·26 ,,	3·46 ,,
,, ...	2·80	1·03 ,,	2·89 ,,
,, ...	3·01	0·613 ,,	1·84 ,,

It is not easy to realise from figures such as the above how minute are the quantities of radium involved; perhaps this may be better done if we consider the largest of these amounts in another way. $9·56 \times 10^{-12}$ gram radium per gram rock is equivalent to 9·56 parts in one billion, or about 1 grain in 6000 tons. It is one of the most remarkable features of modern physical methods that it should be possible to estimate such excessively minute amounts with precision and certainty, amounts not only infinitely beyond the range of chemical detection, but also quite outside the powers of the spectroscope unless the material is first specially concentrated. In a paper on "The Evolution of the Elements," read before the British Association at its last meeting, Mr. F. Soddy remarked :—"The smallest quantity of any element that can be detected by the spectroscope contains 10^{10} individual atoms, whereas the disintegration of a single atom accompanied with the expulsion of one α particle is not greatly, if at all, below the limit of detection by present methods."*

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* See Chemical News xciii., 235 & 247, 25 May and 1 June, 1906.

The radio-activity method is thus in this case something of the order of 10,000,000,000 times more sensitive than the spectroscopic. The former method depends on the intense ionising power of the emanation, whereby air submitted to its action is brought into a state of partial disintegration known as ionisation, in which condition it becomes an active conductor of electricity. The emanation from a known quantity of radium is collected in air during a fixed period, and the conducting power of the air is then determined by suitable means. The same method applied to any specimen under examination gives the relative value from which its radium content can be readily calculated.

Mr. Strutt considers that 5×10^{-12} gram radium per c.c. rock may be taken as a reasonable average for the rocks constituting the earth's crust. Taking the mean density of the rock at 2·7, this would be equal to $1{\cdot}85 \times 10^{-12}$ gram radium per gram rock.

Assuming the internal heat of the earth to be entirely derived from the disintegration of radium uniformly distributed throughout its mass, and taking Lord Kelvin's data for the thermal conductivity of the rocks *in situ*, Mr. Strutt calculates that the amount of radium necessary to account for the observed heat gradient near the surface is about $0{\cdot}175 \times 10^{-12}$ gram per c.c., an amount greatly less than the smallest proportion found in any igneous rock examined. From this and other data he concludes that radium does not exist in the earth's centre, but is confined to a crust not exceeding 45 miles in thickness and that the temperature from that point to the earth's centre is not greater than about 1500°C.(2732°F.).

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* Chemical News xciv., 86, 24 Aug. 1906.

Mr. O. Fisher has examined the subject more in detail.* Taking the two most commonly accepted values for the temperature gradient of the earth's crust at the surface, that of Prestwich, which is 1°F. for each 42·2 feet of descent, and the more modern one of 60 feet for a similar rise of temperature,† he shows that the amount of radium required is a diminishing quantity downwards, which is expressed in the following table:—

Thickness of crust. Miles.	Gradient 1° F. in 42·2 ft.			Gradient 1° F. in 60 ft.		
	Radium content gram per c.c.	Temp. °C.	do. ° F.	Radium content gram per c.c.	Temp. °C.	do. °F.
15	$15{\cdot}39 \times 10^{-12}$	519	966	$10{\cdot}27 \times 10^{-12}$	363	685
20	11·55 ,,	692	1278	8·08 ,,	484	903
25	9·13 ,,	865	1589	6·39 ,,	606	1123
30	7·70 ,,	1038	1900	5·09 ,,	727	1341
35	6·60 ,,	1211	2212	4·62 ,,	848	1558
40	5·77 ,,	1384	2523	3·84 ,,	969	1776
45	5·13 ,,	1557	2834	3·59 ,,	1090	1994

The figures for °F. given by Mr. Fisher are in some cases not in agreement with the °C.; these I have corrected in above table.

Mr. Fisher points out that Professor Bartoli ascertained the temperature of lava flowing from Mount Etna to be 1060°C. (1940°F.), corresponding to a depth of from 30 to 40 miles, according to which of the above temperature gradients is adopted. The 45 miles thickness of crust adopted by Mr. Strutt agrees very well with that arrived at by Professor Milne from a study of the propagation of earthquake waves.

The values for radium content in Mr. Fisher's table come well within the scope of the actual amounts ascertained by Mr. Strutt to exist in accessible rocks.

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* Nature. lxxiv., 11 Oct. 1906, p.585.

† In my address, Proc. Linn. Soc. N. S. Wales, 1905, p.618, I took the mean of these, viz., 51 ft. Prof. Gregory, Chem. News xciv., Sept. 21, 1906, p.143, adopts 55 feet.

Lord Kelvin does not acquiesce in the above theory of earth-heat; he considers it highly probable that the conditions of pressure and environment at a short distance from the earth's surface are sufficient to effectually prevent the disintegration of radium and hence the evolution of heat.*

The heat evolution from 1 gram of radium amounts to 0·6785 British thermal units per hour, or 5944 in a year, which is equivalent to the evaporation of 175 lbs. of water per annum by 1 oz. of radium. The mechanical equivalent of the latter may be expressed as being equal to the raising of 577 tons 100 feet above the earth's surface. It is startling to think that this enormous thermal energy is evolved in the time stated with the loss of but a minute fraction of the weight of the radium involved. Professor Rutherford estimates the energy equivalent of radium as at least a million times that of any other known molecular combination.†

As the most moderate estimate of the quantity of radium in the rocks constituting the earth's crust is amply sufficient to account for the observed heat gradient near the surface, if what I might call the extreme radium theory be accepted as accounting for the present thermal condition of the earth, it becomes necessary to abandon the idea of there being any serious quantity of the original gravitational heat remaining. It is the essence of the extreme radium hypothesis that a condition of thermal equilibrium has been attained, that the earth is neither getting hotter nor cooler and will remain in its present condition so long as the production of radium continues at an adequate rate. That there must be a time limit is obvious, for the supply of uranium or other radium-yielding material cannot be inexhaustible, but considering the enormous energy equivalent of radium, we see that exceedingly small proportions are adequate to yield the required heat for a very long period. The possible extension of time is enormously increased if a recent suggestion of Prof. J. Joly be accepted that the earth may be continuously deriving its supplies of radium from solar emanations.* It is known that the tangential speed of projection of the matter constituting the solar emanations is sufficiently great to carry it out of control of the sun's gravity and into the sphere of influence of the earth. Prof. Joly thinks that this might account for the apparent limitation of radium to the crustal skin of the earth. That other bodies yield analogous disintegration products, accompanied by the evolution of energy, is well ascertained, but in no known case is this activity at all comparable with that of the uranium-radium product. Still, however, it is quite in keeping with modern views that all matter is in a more or less rapid condition of disintegration, and we cannot say how much of the heat of the earth's interior may be due to the aggregate effect of disintegration and transformation in the mass of matter of which it is composed. I mentioned Sir William Crookes' views on this phase of the subject in my address last year.† Possibly the earth's supply of radium-producing elements may be fairly evenly distributed throughout its mass, and disintegration, while not altogether prevented, may be greatly curtailed by environment and pressure. Were this so we might expect a considerably augmented radium production when materials from beneath reach the surface through the agency of volcanic action. This would account for the surface material displaying so much greater radium activity than can possibly be the case throughout the interior of the earth. At the same time such a conception of the place of radium in the scheme of world physics permits of the possible, and, for my part I think, highly probable, retention by the earth of a portion of its original gravitational heat. We should then have a cooling globe masked by a heat-generating crust, the effect of which would be to indefinitely delay the secular cooling of the heated centre.

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* Chem. News. xciv., 21 Sept. 1906, p.145.

† Rutherford, "Radio-Activity," 2nd ed., p.482.

Assuming the heat of the earth's central mass to be due to the original store of gravitational heat, Lord Kelvin has shown that in order to account for the existing heat gradient near the surface an internal temperature of about 7000° F. is required.* This is much higher than the temperatures calculated by Messrs. Strutt and Fisher as being adequate if the central heat is derived from radium contained in the crust. In the one case we have a hot centre cooling outwards, in the other a warm crust also radiating heat outwards, but maintaining its thermal equilibrium by the production of heat from radium. The temperature difference between the two conditions, for the central mass, is a physical necessity, and the estimation of its approximate amount is simply a matter of calculation.

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* Nature, lxxv., 1907, p.294.

† Proc. Linn. Soc. New South Wales, 1905, p.617.

For our present purpose it does not matter whether we adhere to the nebular hypothesis, which, since its enunciation by Laplace and subsequent elucidation by later mathematicians, and notably by Lord Kelvin, has been practically universally accepted, or adopt the accretion theory brought forward by Professor G. H. Darwin in his Presidential Address to the British Association in 1905. According to the latter theory, the earth was built up by the gathering of pre-existing planetoids from its orbital region in space. Either theory is competent to provide ample heat, which is all that is required in our present discussion. In the remainder of this address I will speak of the original heat of the earth merely as gravitational. The planetoids are commonly held to have to a large extent originated from the gravitational disruption of former celestial bodies through these approaching within critical range of one another. This supposition has the merit, against the collision theory, of better explaining the structure of stony and other meteorites, which could not have resisted the inevitable fusion, or even vaporisation, following actual collision.

Professor T. C. Chamberlin, of Chicago, has worked out a very ingenious development of the accretion theory which is full of extremely suggestive ideas, but seems to me to be less convincing than the simpler hypothesis of Professor Darwin.* According to Professor Chamberlin, the accretion of planetoids was in all probability a slow process, so much so that the heat of impact was dissipated about as rapidly as acquired. Hence, he concludes, conditions suitable for the establishment of life may have existed when the earth was but a fraction of its present size. The existence of central high temperature he attributes in part to a remnant of gravitational heat acquired through the primary nucleus having been gathered rapidly when planetoids were relatively abundant, but in the main to the gradual increase in pressure as the globe increased in size. Mere pressure does not produce heat unless it causes change of volume, and it seems doubtful to me that the denser packing and molecular rearrangement through increase in pressure, which Professor Chamberlin assumes, could be sufficient to generate the heat required. He, however, expressly states his conviction of the sufficiency of the cause given, and concludes that the present internal temperature of the earth increases steadily to the centre, which he estimates to be about 20,000°C.(about 36,000° F.). It will be seen that this temperature is greatly in excess of the 7,000° F which Lord Kelvin considers possible for the present surface thermal gradient if due to a cooling hot centre, and still more in excess of the modest 2,700° F. required by Mr. Strutt for a radium-warmed globe.

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* Kelvin, Popular Lectures and Addresses, Vol. ii. 1894, p.313. See also these Proceedings, 1905, p.619.

It is further not at all clear to me how under the conditions postulated by Professor Chamberlin the lunar satellite could come into existence. Professor Darwin concludes that the heat of impact of the planetoids was great enough to cause incandescence of the entire mass of the growing earth, and, as the result of a careful mathematical examination of the problem of a revolving molten mass such as is assumed for the early condition of the earth, finds that the shape acquired will vary with the rate of revolution. At one particular speed it will be of the earth's present shape; at a higher speed the equatorial outline will be an

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Chamberlin & Salisbury, Geology, Vol.ii. 91, 1906.

oval like an egg spinning on its side; at a still higher speed one end will form a projection which will take the form of a neck with a drop at its outer extremity, and, ultimately, this will be thrown off to form a satellite revolving around the parent body. The beauty and suggestiveness of this scheme become all the greater when we reflect that under such circumstances the original mass must, through the tidal action induced by its own offspring, continually decline in its rate of revolution, and assume a shape corresponding to its changed speed, while the satellite will, through reflex action, steadily increase its distance from the parent body.

Although we are accustomed to speak of the earth as being practically a rigid body, we must not lose sight of the fact that it is so merely in a comparative sense, and that the hardest rocks of its crust are sufficiently plastic to permit of the shape of the whole accommodating itself to any change in speed of rotation or indeed to any adequate force continuously applied. The existing equatorial bulge is the result of a definite force due to the period of revolution, and will certainly alter in unison with the gradual decline in the rate of that motion. Could the revolution of the earth be stopped without disruption through inertia, the equatorial bulge would disappear in obedience to gravity, and the earth would become practically globular in shape.

As will be obvious to all, the extreme interest and importance of the development of the radium hypothesis lies in the great extension of time which it permits for biological evolution and geological development. When we limit the habitable age of the earth by the possible time allowable for cooling from its original heated state, very grave difficulties arise as to the possibility of fitting in the requirements of geological time; but in the light of the possibilities of radium it is easy to push back the period of gravitational incandescence until the time occupied in cooling from that condition to one in which the existence of life is possible, becomes but a small fraction of the earth's history. There are, of course, astronomical reasons for placing a limit on the earth's age, but the requirements of astronomy permit of a liberal allotment of time, and there is no reason for limiting the original supply of radium-producing material, and, hence, of the time during which its heat has been available.

It is quite obvious that in the earlier stages of the earth's history, when rapid cooling was taking place, crust movements on a colossal scale must have occurred, and that as cooling proceeded, these would gradually moderate. If we imagine a time when all this heat had disappeared and the earth had arrived at a stage of thermal equilibrium such as is assumed under the extreme radium theory to be its existing condition, it is evident that no more shrinkage could take place and that any display of crust movement or volcanic energy must be due to some other cause. The material of the earth's interior up to a point comparatively near the surface, is, as we know, at a temperature considerably above its surface melting point, but there is evidence that it is retained in a solid state by the pressure of the supernatant strata. Whenever this pressure is relieved liquefaction occurs, and we then have the fused matter squeezed out in the form of lava, through any available opening; or, it may be, forming sheets or dykes at or beneath the surface. We may consider any given land area as floating on a substratum of lava, which, though solid, or perhaps more or less plastic, is ready to respond to relaxation of pressure. It is thoroughly well understood that the surface of the land, and, in particular, the great mountain masses, lose in the aggregate very large quantities of material every year through denudation. The removal of such quantities of matter from one place to another on the earth's surface must have a very considerable effect on regional stability, and will be quite competent to account for extensive earthquake and other movements. When a land surface is stripped by denudation and the material so removed deposited around it, while the pressure of the surface in question is lessened, that of the area receiving the spoil is increased, and the effective force operating in the direction of raising the one area and depressing the other will, in an ideal case, be double the weight of the transferred material.

There appears to me to be much difficulty in accounting for the various observed land movements if these are to be attributed to denudation alone, but if to this source of disturbance be added a moderate amount of shrinkage through secular cooling, all classes of earth movement, folding, &c., can be much better explained. From shrinkage alone, one would expect erratic tilting and sinking, but not orderly regional uplifting or subsidence, and it seems probable that such movements are in the main due to denudation. Land may readily enough sink through denudation in spite of the attendant removal of pressure, because that very relief may bring about the liquefaction of lava previously held solid by pressure, while the accompanying disturbance opens up channels for its escape.

It has during recent years been increasingly manifest that much volcanic activity is caused by the penetration of ocean water through earthquake fissures to the interior hot part of the earth, with the consequent production of steam at very high tension. Large quantities of hydrogen chloride are at times emitted by volcanoes, and, it being now pretty well known that existing plutonic waters are practically free from chlorine, the obvious source of supply of this substance is the salt of the ocean water.*

It has been suggested that if the crust of the earth contains sufficient radium to provide the heat known to exist in the interior, the moon, from its supposed mode of origin, must also be equally rich in radium, and should indeed have an even greater internal heat than the earth. This question has been very satisfactorily dealt with from the extreme radium standpoint by the Hon. Mr. Strutt,† who points out that though the period of lunar volcanic activity has been generally believed to be past, much doubt has been thrown on this assumption by the observations of modern astronomers, and notably by Professor W. H. Pickering, who is decidedly of the opinion that changes sufficiently great to be noted occur from time to time on the moon's surface. That these changes are not more commensurate with the probable internal heat, may well be because of the absence of water. If it be the case that terrestrial volcanic action is largely induced through atmospheric denudation and oceanic penetration, then the absence of water and of atmosphere from the moon would sufficiently account for her comparative surface stability, and if to the original gravitational heat be added radium blanketing, then, as in the case of the earth, we can readily admit a prolonged condition of internal high temperature, and the absence of any serious amount of disturbance from shrinkage due to secular cooling.

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* See references, Proc. Linn. Soc. N. S. Wales, 1905, p.621.

† Proc. Roy. Soc. London, A lxxvii. 472.

If the presence of radium is admitted as a factor in the thermal evolution of earth and moon, it is but a natural step to apply the same reasoning to the sun and thereby to open up a vista of time for the entire solar system greatly in excess of anything hitherto considered by physicists to be admissible.

Carbon Dioxide and Geological Climate.—For some years past a good deal of attention has been devoted to the question of the influence on climate of possible variations in the composition of the atmosphere as regards its carbon dioxide and moisture contents, and more especially on the competency of such variations to induce the great climatic changes which are involved in the transition from conditions even warmer than those which are now experienced in temperate regions, to a state of glaciation sufficiently severe to partially invade the tropics. I propose to outline the principles underlying this problem and to show in what manner the effect described might be brought about by the specified changes in atmospheric constitution. In all that follows regarding the carbon dioxide theory of glaciation, I do not wish to be understood as entirely indorsing all the details given. The hypothesis seems to me a very beautiful and suggestive one, and my desire is to give, as far as I am able, a concise account of its salient features, leaving my hearers to form their own opinions as to its adequacy as a cause of the observed phenomena. Professor Chamberlin has elaborated this hypothesis in a series of extremely valuable papers full of luminous suggestion, which should receive the most careful study from all interested in the great questions of earth history, and to which I am much indebted.*

The idea that glaciation over a wide range of the earth's surface could be caused by removal of carbon dioxide and concurrently of water vapour from the atmosphere, is by no means novel. It appears to have been first suggested by Professor Tyndall, who was led thereto by the result of his observations on the thermal properties of gases and vapours. Tyndall found that while simple gases such as nitrogen and oxygen, which constitute the bulk of the existing atmosphere, are extremely transparent to the entire solar emanation of light and heat, compound gases like carbon dioxide, marsh gas, ammonia, &c., and the vapours of water, alcohol, essential oils, &c., differentiate between the various wave lengths, and, while allowing some to pass as freely as do the simple gases, offer greater resistance to the passage of others. The waves which are unable to pass through the compound gases and vapours are the long obscure ones in the ultra-red, while the shorter waves above this pass freely. Even in very moderate thickness such gases are able to effectually bar the progress of considerable quantities of obscure heat.

As a matter of fact no sharp distinction can be drawn between heat and light, the waves of the former passing insensibly into the latter as we progress along the spectrum. Light waves differ from one another and from those of heat merely in their length, and, as all progress through space at equal rates, it follows that the shorter waves give a greater number of impacts to a receiving surface in unit time, than do the longer. The longest waves, giving the fewest impacts in unit time, are the obscure heat rays of the ultra-red, and as we pass on towards the visible spectrum the waves become shorter and shorter, and constitute what is commonly called radiant heat.

Professor Tyndall was the first to put the matter of the selective action of gases upon radiant energy on a proper foundation, and the results of his classic researches, as detailed in his published lectures, may still be considered as the clearest and most illuminating account of the phenomenon in question.* The cause of this difference in behaviour of the two kinds of gases lies in the fact that the simple gases do not respond to the vibrations of the portion of the spectrum carrying the heat waves; they behave to these much as they do to the still shorter waves of visible light: while on the other hand, the larger molecules constituting the compound gases, while quite as transparent to the light waves as those of the simple gases, are capable of vibrating in unison with the obscure heat waves, and so, by transferring the energy of these to themselves, offer an effectual barrier to their progress. The action of the compound gases towards obscure heat rays is much the same in character as that of a sheet of metal when placed so as to intercept the heat from a fire; the metal is capable of responding to the vibrations of the heat waves, and so absorbs their energy to produce heat vibration in its own substance.

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* Jour. Geol. Vols. v. and vii., 1897 and 1899.

We may now very briefly consider a very interesting phenomenon, the acceleration or retardation of the waves of radiant energy when the body emitting them is moving in a direction to or from the observer. A very commonly noticed analogous case is the sharpening or flattening of the pitch of a railway whistle when approaching or receding. If the source from which the radiant energy is being emitted be approaching the observer, the waves right along the spectrum are accelerated by the precise amount of the forward motion, while the radiation from a receding body will be drawn out or retarded. A ray from a stationary body, which reaches the eye as yellow, will, from a body approaching at a sufficiently rapid rate, be accelerated, and appear as some colour nearer the blue, while from a receding source it will be retarded in the direction of the red. Obviously, any absorption lines in the light from a body moving in the line of sight, will be displaced in one direction or another, according to the rate of travel of the body, and thus furnish a means of telling the direction and speed of motion. It is further evident that waves beyond the visible spectrum at one end or the other may be brought into the visible range by acceleration or retardation. So also, rays belonging to the visible red end may be changed into invisible heat, or others at the blue end may be pushed forward and accelerated into invisible chemical rays.

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* Tyndall, "Heat a Mode of Motion," 6th ed., 1880, p.321 *et seq.*

The temperature of a heat-emitting body has a direct influence on the nature of the heat evolved. The hotter the body the more nearly the heat waves approach the properties of red light, while the cooler the body the more they tend to become obscure. All heat given off from a body of the nature of the earth is of the obscure type. Radiant heat is not reflected as such but is degraded and sent away in the lower form.

We may now picture the earth's atmosphere, containing carbon dioxide and water vapour, with the sun's radiant energy pouring into it. The long waves of obscure heat will be absorbed in the upper layers of the atmosphere, leaving the shorter waves of radiant heat to pass on and reach the surface of the earth, where they are at once absorbed, partly by the solid and partly by the aqueous surface. The warmed solid surface proceeds to part with its heat by radiation and contact with the air, the heat emitted being now of the obscure type, and so unable to pass the carbon dioxide and water barrier. The result is that the lower layers of the atmosphere become warmed by the transformed heat which before passed freely through. The fate of the heat taken up by water is mainly to cause evaporation, whereby it is carried in the latent state in the water vapour and liberated where the vapour condenses to form clouds, the ultimate result being, that like that absorbed by the land, it goes to warm the atmosphere. Finally the heat acquired by the atmosphere is scattered in all directions, some back to the earth, some laterally to the surrounding portions of the atmosphere, and some into space. A condition of equilibrium is then established, the earth losing heat at the same rate as it is received, but with the vastly important provision that its own surface remains at a temperature high enough to give what I might term heat pressure sufficient to penetrate the obstructing atmospheric blanket. The less of the efficient heat-trapping carbon dioxide and water vapour are contained in the atmosphere, the lower will be the surface temperature necessary to produce a state of equilibrium, and hence, the colder will be the climate at the earth's surface, and, conversely, the more carbon dioxide and water present in the air, the higher will be the temperature. The carbon dioxide may be considered as the controlling factor in determining the absorptive power of the atmosphere for heat, for, although water vapour has probably a greater actual effect, it depends entirely on temperature for its presence, while carbon dioxide is not directly affected by the temperature changes which it itself induces. When carbon dioxide is removed the temperature falls, and with fall in temperature the proportion of water vapour decreases; such decrease is followed by a further fall in temperature which again robs the atmosphere of more water vapour, and this process goes on until the lowest temperature which the carbon dioxide will permit is reached, and a condition of thermal equilibrium is set up. When carbon dioxide is increased the temperature rises, and with rise of temperature the capacity of the atmosphere for holding water is augmented, and thereby a further rise in temperature is brought about until by alternate action and reaction thermal equilibrium is again established. We thus see that the carbon dioxide is the dominant element, and in what follows I will for the sake of simplicity speak of the temperature changes as if entirely due to carbon dioxide variation.

The greatest step in advance within recent years, in the development of the carbon dioxide hypothesis, is due to Professor Arrhenius, who, as the result of an extremely able and laborious mathematical examination of the problem, has shown that a certain reduction in the proportion of carbon dioxide now present in the atmosphere would, in so far as can be seen, be competent to bring about a sufficient fall in the average temperature at the earth's surface to produce glaciation to latitudes as low as to be well within the tropics.* Arrhenius bases his calculations on the work of Professor Langley on the determination of the variations in the amount of heat received from the full moon when at different altitudes above the horizon and thus shining through varying thicknesses of atmosphere.

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* Arrhenius, Phil. Mag. (Ser. 5), Vol.xli. 1896, p.237.

Professor Chamberlin assumes that even in early Palæozoic times the atmosphere did not materially differ from its present composition, there having always been a conflict between sources of supply and causes of depletion of carbon dioxide. The amount of this constituent in the existing atmosphere varies somewhat in different regions, but may be stated as averaging about 0·03 per cent. by volume. Arrhenius has calculated that a reduction sufficient to bring this down to 0·016 to 0·018 per cent., or the removal of rather more than one half, would suffice to reduce the mean temperature by an amount equivalent to 7 to 9° F., which would mean the extension of glacial conditions to within about 20° on either side of the equator; while an increase of from 2½ to 3 times the present proportion, bringing the carbon dioxide content to 0·075 to 0·090 per cent., would result in an increase of the mean temperature by 14 to 16° F., and give semitropical conditions well within the arctic and antarctic zones. In support of the possibility of such variation in atmospheric carbon dioxide, Arrhenius quotes the opinions of Professor Högben who has published in a Swedish journal* the result of his studies on the probable sources of supply and causes of depletion of this gas to and from the atmosphere. Högben considers that the atmosphere is and has always been continuously supplied with carbon dioxide, amongst other gases, from the earth's interior. Such supplies would be quite independent of surface conditions, and would continue even during periods of extreme glaciation. This is the important point on which the whole theory depends.

That there are large supplies of carbon dioxide available is well known. Examination of numerous volcanic and metamorphic rocks has shown that they contain, on an average, several times their own volume—at atmospheric pressure—of permanent gas. There is no difficulty at all about proving the presence of this gas in ordinary rock. All that is required is to heat the rock in small fragments in an exhausted flask, when the gas is given off and can be measured and its composition ascertained. The gas is usually contained in minute cavities throughout the body of the rock, and but little of it escapes even on grinding. That it must be under very great pressure is evident from the volume to which it expands when liberated. Sir William Crookes, in his lecture on Diamonds, delivered before the British Association meeting at Kimberley, mentioned that diamonds frequently explode soon after reaching the surface, or on being gently warmed, owing to the pressure exerted by globules of inclosed gas.* Professor Tilden has thrown much light on the quantity and composition of the gases occluded in rocks, in a paper read before the Royal Society some years ago.† His examination covered a large number of examples of granite, schist, gneiss, basalt, &c., in which he found gas varying from 1·3 to 17·8, and averaging about 5 times, the volume of the containing rock. In a general way hydrogen was found to be the most abundant constituent, but carbon dioxide was also invariably present in large proportion. One series of rocks gave the following average figures for the composition of the contained gas :—

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* Svensk Kemisk Tedskrift, 1894, p. 169.

Hydrogen	...	52·2
Carbon dioxide	...	34·1
,, monoxide	...	8·4
Marsh Gas	...	3·2
Nitrogen	...	2·1
		100·0

In another and larger series the mean composition was :—

Hydrogen, &c.	...	73·8
Carbon dioxide	...	26·2
		100·0

At this rate it is a simple matter to show by calculation that the rocks within a very moderate distance of the earth's surface contain more gas than would supply several times the volume of the existing atmosphere, and if the entire mass of the earth be assumed to contain gaseous matter in the same ratio, sufficient is in existence to form many hundred atmospheres. Carbon dioxide is known to be evolved in immense quantities from volcanoes and to be also extruded from the rock walls in mines, from springs, from the surface soil and from innumerable caves, one of the best known of which, perhaps, is the Grotta del Cane, near Naples, where dogs are rendered insensible and lights extinguished by the layer of gas on the floor of the cave. It seems reasonable to admit that in these we have a sufficient source of supply for what, though aggregating many millions of tons of carbon dioxide annually, is relatively but a small quantity in comparison with the amount existing in the atmosphere at any one time.

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* Chem. News, xcii. 1905, p.159.

† Chem. News, lxxv. 1897, p.169.

The causes of loss of carbon dioxide may be divided into temporary and permanent. Of the former, absorption by the waters of the ocean and fixation by living organisms may be considered the most important. The great cause of permanent loss will be the withdrawal of carbon dioxide through its action in weathering the surface of the land, which is acting continuously wherever moisture and air have access to rocks and soil. In the case of the carbon dioxide taken up by the ocean, we have seen that this source of loss varies in activity with the temperature of the water, and that with rise in temperature the borrowed gas is returned to the atmosphere. By far the greater proportion of the carbon taken up and fixed in the tissues of living organisms is returned to the air again, for the balance of life and death remains unchanged. It is true that in coal deposits great quantities of carbon have been permanently fixed, but even the total of this, on a liberal estimate, amounts to but a tiny fraction of the world's stock, and in any case such fixation could but take its place along with the other sources of permanent removal and merely have effect in delaying the change from one climatic state to another. The carbon fixed in coral, limestone and similar formations aggregates a much greater proportion of the whole than that locked up in coal, but as all of this is derived from the fixed portion of that captured by the ocean, or in some cases by freshwater lakes, and hence not available for return to the air, the form in which it is stored is of no consequence so far as glacial changes are concerned. It is in the consumption of carbon dioxide in the weathering of rocks that the great primary source of permanent loss lies. The rocks constituting the exposed surface are largely composed of silicates and by the action of carbon dioxide and moisture these are decomposed, the bases combining with the carbon dioxide and ultimately finding their way into the ocean. Practically all the carbon dioxide so fixed may be considered as permanently lost.

We have seen that depletion of atmospheric carbon dioxide induces a cold surface condition while enrichment results in the opposite effect. When the land surface is at work removing carbon dioxide and thereby bringing about cooling, and the ocean, responding to the change, aids in the withdrawal, all the conditions necessary for the inauguration of a glacial epoch are present, and, accordingly, when the rate of removal of carbon dioxide exceeds that of supply, it is only a matter of time for the change to occur. With the advent of an icy covering the land would be effectually shielded from the action of atmospheric carbon dioxide, and the loss through weathering being stopped, or at any rate greatly reduced, a time of steady accumulation would set in, resulting in the dawn of a genial period; the encroachment of ice would be stopped, the line of glaciation driven back towards the poles, and the rocky surface again exposed. On the completion of one cycle there would be a gradual swing in the opposite direction, and so the continued succession of glacial and warm periods, of which we have evidence, would be accounted for.

There are so many modifying influences, such as variation in the relationship of water and land, which would tend in one way or another to affect the rate and intensity of climatic change as well as the time of duration of both conditions, that nothing in the way of regular periodicity is to be expected in glacial epochs, and that there was no such periodicity seems to be the trend of the evidence. Partial retreats and advances of ice, and greatly varying rates of change have undoubtedly been the rule. At the present time all the indications appear to point to the world's being in the waning stage of a glacial period, so that warmer conditions are now steadily invading the circumpolar regions.

The question naturally arises at this stage, what would be the effect of the escape of internal heat from the earth in aiding the carbon dioxide of the atmosphere to maintain a genial climate. This problem was long ago dealt with by Sir William Thomson (Lord Kelvin), who arrived at the result that, starting with an incandescent globe, "the general climate cannot be sensibly affected by conducted heat at any time more than 10 000 years after the commencement of superficial solidification."* The same authority elsewhere says: "Ten, twenty, thirty times the present rate of augmentation of temperature downwards could not raise the surface temperature of the earth and air in contact with it more than a small fraction of a degree Fahrenheit. The earth might be a globe of white-hot iron covered with a crust of rock 2,000 feet, or there might be an ice-cold temperature everywhere within 50 feet of the surface, yet the climate could not on that account be sensibly different from what it is, or the soil be sensibly more or less genial than it is for the roots of trees or smaller plants."†

The view has been held by some observers that the internal heat of the earth was a sufficient source of warmth to maintain a uniform genial climate over the entire surface of the globe during long periods of geological time, and that the sun's heating influence during these periods was effectually neutralized by impenetrable banks of cloud. The ocean was supposed to be kept warm by contact with the heated earth.‡ Lord Kelvin, as is seen from the above quotations, gives absolutely no support to this theory. Likewise regarding the belief that the rate of cooling of the earth's interior is sensibly affected by variations in the amount of heat received from the sun, with consequent manifestation of earthquake action due to increased shrinkage, when, through any cause, there is a falling off in the amount of sun heat received. This position seems to me equally untenable. It is well known that the heat of the sun does not affect the temperature of the soil more than a few feet from the surface, and in the light of Lord Kelvin's work, it appears certain that no variation in surface temperature within even far wider range than is now experienced, can have any sensible effect on the rate of transmission of heat outwards from the interior. Were it the case that mere change in surface temperature had any such effect, we should surely have distinct manifestations of differential shrinkage every winter, through the unequal loss of heat following the change of season. To me it seems that unequal loss of heat through winter ruling in one hemisphere while summer was warming the other, would be far more likely to induce earthquake tremors than even a very considerable increase in the rate of heat loss, uniformly distributed.

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* Mathematical and Physical Papers, Vol. iii., 1890, p.305.

† Trans. Geol. Soc. Glasgow, Vol. v., Part ii., 1877, p.250. Kelvin, Popular Lectures and Addresses, Vol. ii., 1894, p.297

‡ See, for example, Manson, 'The Evolution of Climates,' The American Geologist, 1898.

In coming to a conclusion on this matter, it will, perhaps, be helpful to consider what is the actual amount of heat escaping from the interior of the earth. Taking the recognised values for heat conductivity of the crustal rocks and for heat gradient near the surface, Lord Kelvin has shown that the loss of heat amounts to about 92 horse-power per square kilometre.* This may be stated in another way, which will, perhaps, convey a more distinct impression to the mind. A horse-power is equal to the raising of 33,000 lbs. one foot high per minute, and 92 horse-power per square kilometre is the equivalent of the evaporation of 10½ lbs. of water per square mile of surface per minute. Even allowing a considerable margin of error for assumed mean conductivity and heat gradient, the result would be of the same *order*, and as it stands may thus be taken as fairly representing the actual state of matters. A fluctuation in the outflow of heat of 10 per cent. would be equivalent to 1 lb. more or less water evaporated per square mile per minute. It may be safely said that one active volcano will dispose of more heat in a day than many hundred square miles of earth surface in a year.

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* Trans. Geol. Soc. Glasgow, Vol. iii. Part ii., 1869, p.234. Popular Lectures and Addresses, Vol. ii., 1894, p.116.

That the glaciation of the earth's surface at any period since palæozoic times cannot have been more than partial, is evident, for were this condition to extend over the entire tropical regions there would remain no sanctuary for the higher forms of life, with the result that all plants and animals unable to withstand the rigours of an arctic climate would perish. That this has not been the case is amply proved by the known continuity of highly developed organisms succeeding one another through long geological epochs covering numerous periods of glaciation. Darwin was much impressed with the importance of glacial mutation as explaining the present distribution of Alpine organisms.*

The plants, for example, found in Alpine regions everywhere over the earth's surface, bear a striking resemblance to one another, indeed, identical species may be found in places widely separated by tracts of country having a climate utterly prohibitive of migration for these, Alpine plants being peculiarly intolerant of other than Alpine conditions. The flora of high latitudes is truly Alpine in character, and similar plants are found flourishing on the European Alps and in the regions fringing the Polar Seas. Any change of climate one way or another must have been gradual. If we imagine an era of glaciation spreading towards the tropics, we can see that for long periods the low level areas would have a climate quite suitable for the growth of Alpine types. In fact the lower levels would constitute a haven for the Alpine flora driven from the mountains by perpetual snow and ice, and thus a region for mingling and for migration would be provided. With the gradual return of genial conditions the plants would migrate back to the mountain fastnesses while the plains which had been clothed with Alpine forms would once again be peopled with appropriate denizens which had taken refuge in the equatorial zone from the cold conditions ruling everywhere else. By a process such as this we can understand how isolated mountains in various tropical areas could come to possess a common flora. Under suitable conditions of land configuration the zones around the polar regions would form a recruiting ground from whence the plants could spread tropicwards as the climate became suitable for their welfare, and to the same hospitable regions the cold-loving forms would be driven back by the return of warm conditions to the lower latitudes. There are sufficient mountain chains crossing the equatorial region to act as bridges by which transmigration could take place. For the sake of simplicity I have spoken only of plants in the above scheme, but obviously animals would equally share the facilities for migration, though the conditions on isolated mountain fastnesses would inhibit the survival there of animals to a much greater degree than plants; hence the large arctic mammals, land and amphibious, to most of which the proximity of the sea or the range of great land areas is absolutely necessary, would naturally gravitate to the regions where they are now found. Glacial mutations and attendant land and ocean configuration alterations, must at all times have been exceedingly powerful aids towards many of the radical changes in type of the flora and fauna characteristic of the transition from one geological epoch to another.

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* Origin of Species, 6th ed., p.330.

In taking leave of the honourable position in which you were good enough to place me two years ago, let me tender my heartiest thanks for the generous support and encouragement accorded me at all times at our meetings and in the conduct of the Society's affairs, and once again to ask you to join me in the sentiment

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Mr. J. R. Garland, M.A., Hon. Treasurer, presented the balance sheet for the year 1906, duly signed by the Auditors; and he moved that it be received and adopted, which was carried